System Dynamics as a Foundation for Pre-College Education

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Abstract: Educational systems are serving poorly. The public response is apt to call for more of what is already not working, rather than seeking fundamentally new and more effective approaches to education. Promising new approaches are now being successfully demonstrated—system dynamics as a framework for giving cohesion and meaning to individual facts, and "learner-directed learning" to harness the creativity, curiosity, and energy of young people. Together these reverse two fundamental roadblocks in traditional education. System dynamics reverses the educational sequence where deadening years of learning facts precede the use of those facts. Systems thinking through computer simulation introduces synthesis (putting it all together) based on facts that even elementary school students already have gleaned from life. Learner-directed learning reverses the process of a teacher's lecturing facts at resistant students; learners take the leadership in exploration, information gathering, and creating a unity out of their educational experiences with the "teacher" acting as guide and participating learner and as a resource person.

Education in the United States is generally recognized as serving less and less well in meeting modern needs. Failures in education appear in the form of corporate executives who cannot cope with the complexities of growth and competition, government leaders who are at a loss to understand economic and political change, and a public that supports inappropriate responses to immigration pressures, changing international conditions, rising unemployment, the drug culture, governmental reform, and inadequacies in education.

There is danger that growing criticism of U.S. education will focus attention on incorrect diagnoses and ineffective treatments. The weakness in education arises not so much from poor teachers as from the inappropriateness of the material that is being taught. Students are stuffed with facts but without having a frame of reference for making those facts relevant to the complexities of life. Responses to educational deficiencies are apt to result in demands for still more of what is not working—for more science, humanities, and social studies in an already overcrowded curriculum—rather than moving toward a common foundation that pulls all fields of study into a unity that becomes mutually reinforcing and far easier to teach and to understand.

Source of Educational Ineffectiveness

Education is fragmented. Social studies, physical science, biology, and other subjects are taught as if they were inherently different from one another even though dynamic behavior in each rests on the same underlying concepts. For example, the dynamic structure that causes a pendulum to swing is identically the same as the core structure that causes employment and inventories to fluctuate in a product-distribution system and in economic business cycles. Humanities are taught without relating the dynamic sweep of history to similar behaviors on a shorter time scale that the student can experience in a week or a year.

High schools teach a curriculum from which a student is expected to synthesize a perspective and framework for understanding the social and physical environment. But that framework is never explicitly taught. A student is expected to create a unity from the fragments of the educational experience. But the teachers themselves have seldom achieved that unity.

Missing from most education is a direct treatment of the time dimension. What causes change from the past to the present and the present to the future? How do present decision-making policies determine the future toward which we are moving? How are the lessons of history to be interpreted to the present? Why are so many corporate, national and personal decisions ineffective in achieving their intended objectives? Such understanding will seldom be revealed by conventional educational programs. Answers to such questions about how things change through time lie in the dynamic behavior of social, personal, and physical systems. Dynamic behavior, common to all systems, can be taught as such. It can be understood.

In education we have been teaching static snapshots of the real world. But the world's problems are dynamic. The human mind grasps pictures, maps, and static relationships in a wonderfully effective way. But in systems of interacting components that change through time, the human mind is a poor simulator of behavior. Mathematically speaking, even a simple social system can represent a tenth-order, highly nonlinear, differential equation. Mathematicians can not solve the general case for such an equation, and no citizen, manager or politician can reliably judge its behavior by intuition. Yet, even a junior high school student with a personal computer and coaching in dynamic behavior can advance remarkably far in understanding such complex systems.

Education faces the challenge of undoing and reversing much that a person has learned by observation of simple dynamic situations. Simple experiences in everyday life deeply ingrain lessons that are deceptively misleading in dealing with more complex social systems. For example, from burning our fingers on a hot

stove, we learn the lesson that cause and effect are closely related in both time and space—we burn our fingers here and now when we move too close to the stove. Almost all understandable experiences reinforce the belief that causes are obviously related to results. But in more complex systems, the cause of a difficulty is usually far distant in both time and space—the cause is back in time and lies in a different part of the system from the point where the symptoms appear. To make matters even more misleading, a complex feedback system usually presents what we have come to expect, an apparent cause that lies close in time and space to the symptom, whereas that apparent cause is usually only a coincident symptom through which there is little leverage for producing improvement. Education does little to prepare students for living successfully when simple, understandable lessons so often point in exactly the wrong direction in the complex real world.

Cornerstones for a More Effective Education

Two mutually reinforcing developments now promise a learning process that can enhance breadth, depth, and insight in education—system dynamics and learner-directed learning.

System Dynamics

During the last 30 years, the field of system dynamics has been building a more effective basis than previously existed for understanding change and complexity. The field rests on three foundations:

1. The growing knowledge of how feedback loops, containing information flows, decision making, and action, control all change in systems—stability, goal seeking, stagnation, decline, and growth. We are surrounded in everything we do or observe by feedback systems. A feedback process is one in which action affects the condition of a system and that changed condition

affects future action. Human interactions, home life, politics, management processes, environmental changes, and biological activity all are surrounded and governed by feedback loops that connect action to result to future action.

2. The use of digital computers, now primarily personal computers, to simulate the behavior of systems that are too complex to attack with conventional mathematics, verbal descriptions, or graphical methods. High school students, using today's computers, can deal with concepts and dynamic behavior that only a few years ago were restricted to the realm of advanced research laboratories.[1]

3. The realization that most of the world's knowledge about structures that give rise to dynamic behavior resides in people's heads. The social sciences have relied too much on measured data and, as a consequence, have failed to make adequate use of the data base on which the world runs—the information gained from living experience, apprenticeship, and participation. Junior high and high school students already have a vast amount of operating information about individuals, families, communities, and schools that can become the basis for accelerated learning about the dynamics of social, business, economic, and environmental behavior.

The system dynamics approach has been successfully applied to behavior in corporations, internal medicine, fisheries, psychiatry, energy supply and pricing, economic behavior, urban growth and decay, environmental stresses, population expansion and aging, training of managers, and education of primary and high school students.

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[1] For most work at the pre-college level, STELLA™ on Macintosh computers is easiest to use. The *Academic User's Guide to STELLA™* is an excellent text book for system dynamics as well as for the software (Richmond, et al 1987). For more advanced professional use, DYNAMO™ is available for IBM and compatible computers (Pugh 1983, and 1986). Several other software packages exist for system dynamics modeling, some with special attention to use in secondary schools.

In pre-college education, Nancy Roberts first demonstrated system dynamics as an organizing framework at the fifth and sixth grade levels (Roberts 1975). Her work (summarized in Roberts 1978) showed the advantage of reversing the traditional educational sequence that normally progresses through five steps from first learning facts to step four on analysis and step five of synthesis. Most students in our educational system never reach that fifth step of synthesis. Synthesis—putting it all together—can come much earlier in the educational process. By the time students reach junior high school they already possess a wealth of facts about family, interpersonal relations, community, and school. They are ready for a framework into which the facts can be fitted. Unless that framework, or structure, is provided, teaching more and more facts loses its significance.

In his penetrating discussion of the learning process, Bruner states, "the most basic thing that can be said about human memory... is that unless detail is placed into a structured pattern, it is rapidly forgotten" (Bruner 1963, p. 24). For most purposes, such a structure is inadequate if it is only a static framework. The structure should show the dynamic significance of the detail—how the details are connected, how they influence one another, and how past behavior and future outcomes are influenced by decision-making policies and their interconnections.

System dynamics can provide that dynamic framework to give meaning to detail, facts sources of information, and human responses. Such a dynamic framework provides a common foundation beneath mathematics, physical science, social studies, biology, history, and even literature.[2]

In spite of the potential power of system dynamics, it could well be ineffective if introduced alone into a traditional educational setting in which students passively receive lectures. System dynamics can not be acquired as a

[2] I have recently been moved to add literature to this list after reading about the powerful impact on students from a computer simulation of the psychological dynamics in Shakespeare's *Hamlet* (Hopkins 1990).

spectator sport any more than one can become a good basketball player by merely watching the game. There must be active participation for the dynamic paradigm to be absorbed, internalized and made a part of a person's controlling mental models. Learner-directed learning offers a participative process that has demonstrated promise of providing the bridge that connects systems concepts to systems thinking.

Learner-Directed Learning

Listening to lectures is for students a deadening, nonparticipating, undemocratic, authoritarian process. It has the disadvantages we normally associate with authoritarian governments. The recipients of such lectures naturally resist authority, they sabotage the process, and their rebellion defeats the best intentions of the educational system.

"Learner-directed learning," is a term I heard indirectly from Mrs. Kenneth Hayden of Ideals Associated.[3] It shifts the role of teacher from being a dispenser of knowledge for students as passive receptors to a mode where small teams of students work together to help one another and the "teacher" becomes a learning participant acting as guide and resource person, not as an authoritarian figure who is dictating each step of the educational process.

Perhaps the best way to glimpse the learner-directed learning process it to hear from a few of those who have first-hand experience:

> From a "citizen champion" engaged in drawing all participants in the school enterprise together in their thinking about a new kind of education, "the use of computers in the classroom (not in a computer lab) has, for us in Tucson,

[3] Ideals Associated, P.O. Box 36988, 2570 Avenida de Maria, Tucson, AZ 85740-691288 is a very small foundation that for two decades has fostered an approach to learning that enlists students themselves in active participation that contributes to the momentum of the educational process.

resulted in a very unique learning environment... (students) learn what they need to know as the teacher guides them in conducting a simulation in class. They work in groups, two or three to a computer—certainly not one per computer—and thereby help one another. Dr. Barry Richmond says that this situation, in effect, multiplies the number of teachers by the number of students. Before doing a simulation the students spend several class periods gathering information about the topic; they take notes during lectures, learn about a library and read references, and, working as a group, plan the simulation. By working this way Draper's students do not merely try to remember the material for a test but actually have to use it in a project simulating real life situations. This has led us to identify a new teaching paradigm which we define as "SYSTEM THINKING with LEARNER DIRECTED LEARNING." (Brown 1990)

From a teacher of 8th grade biology, "Since October 1988 our classrooms have undergone an amazing transformation. Not only are we covering more material than just the required curriculum, but we are covering it faster (we will be through with the year's curriculum this week and will have to add more material to our curriculum for the remaining 5 weeks) and the students are learning more useful material than ever before. "Facts" are now anchored to meaning through the dynamic relationships they have with each other. In our classroom students shift from being passive receptacles to being active learners. They are not taught about science per se, but learn how to acquire and use knowledge (scientific and otherwise). Our jobs have shifted from dispensers of information to producers of environments which allow students to learn as much as possible.

"We now see students come early to class (even early to school), stay after the bell rings, work through lunch and work at home voluntarily (with no assignment given). When we work on a systems project—even when the students are working on the book research leading up to system work—there are essentially no motivation/discipline problems in our classrooms." (Draper 1989)

From a teacher of literature to high-school juniors in a slower-track group where previously few of the students had shown even a slight interest in anything like a play by Shakespeare, "(when we used) a STELLA model which analyzed the motivation of Shakespeare's Hamlet to avenge the death of his father in HAMLET... The students were engrossed throughout the process... The amazing thing was that the discussion was completely student dominated. For the first time in the semester, I was not the focal point of the class. I did not have to filter the information from one student back to the rest of the class. They were talking directly to each other about the plot events and about the human responses being stimulated. They talked to each other about how they would have reacted and how the normal person would react. They discussed how previous events and specific personality characteristics would affect the response to each piece of news, and they strove for precision in the values they assigned for the power of each event. My function became that of listening to their viewpoints and entering their decisions into the computer. It was wonderful! It was as though the use of precise numbers to talk about psychological motives and human responses had given them power, had given them a system to communicate with. It had given them something they could handle, something that turned thin air into solid ground. They were directed and in control of learning, instead of my having to force them to keep their attention on the task." (Hopkins 1990)

The Present Status

The field of system dynamics is developing rapidly, but does not yet have widespread public visibility. The international System Dynamics Society was formed about five years ago. Its membership has grown rapidly to some 300. Annual system dynamics international meetings have been held for fifteen years with the most recent in Norway, Colorado, Spain, China, California and Germany. System dynamics books and papers are regularly translated into many languages including Russian, Japanese, and Chinese.

After 30 years of development, several dozen books have been written on the theory, concepts, and applications of system dynamics. Some have exerted surprising public impact. *The Limits to Growth* book (Meadows, et al 1972), dealing with population, industrialization, hunger, and pollution, has been translated into some 30 languages and has sold over three million copies. Such wide-spread readership of a book based on computer modeling testifies to a public longing to understand how present actions lead into future difficulties and successes.

System dynamics was developed at M.I.T. The first leaders in the field were educated there. But competence is now appearing in many places. Talent exists on which to build a new kind of educational system.

But, system dynamics is so broadly applicable throughout physical, social, biological, and political systems that the small number of experts have been thinly dispersed over a wide spectrum without yet generating a strong critical mass in any one area. So it is with the application of system dynamics to pre-college education. Initial work is under way in several places, but progress has not yet reached a point where it has clearly demonstrated a self-sustaining momentum in the absence of a strong input from a person broadly knowledgeable about system dynamics.

Several high schools, curriculum-development projects, and colleges are beginning to build study units in mathematics, science, social studies, and history around a system dynamics core. These have not yet reached the point of becoming a fully integrated educational structure.

The most advanced experiment in the United States in bringing system dynamics and learner-directed learning together into a more powerful educational environment appears to be in the Catalina Foothills School District of Tucson, Arizona. In that community the necessary building blocks for successful educational innovation seem to be coming together. These involve fundamental

new concepts of education, a receptive community, talented teachers who are willing to try unfamiliar ideas and who are at ease in the nonauthoritarian environment of learner-directed learning, an understanding and encouraging school administration, a supportive school board, and a "citizen champion" who without a personal vested interest in the outcome except for a desire to facilitate improvement in education has helped by inspiring teachers, finding funding, arranging for computers, and above all facilitating convergence of the political processes in the community.

Some other countries (Norway, Germany, Japan, and China) appear to be moving ahead in using system dynamics as a foundation for designing a more powerful educational system below the college level. Even though this new basis for education was developed in the United States, there is, as has earlier occurred in technological developments, a possibility that countries in Europe and the Orient may advance more quickly to effective use.

The Future

Over a period of several decades, we can expect an improved kind of educational system to evolve even without special action. But should we wait? The growing severity of corporate, economic, social, political, and international difficulties demonstrates an acute need for better understanding. Aggressive action can lead sooner to a society with keener insights into the reasons for current shortcomings and how to evolve more effective social systems for the future.

The foundation now exists for a far more effective educational program. But a vast amount of work is still needed to build on that foundation. Adequate educational materials are yet to be developed. One book exists aimed especially at high schools (Roberts, et al 1983). Other introductory system dynamics books are

available.[4] Nevertheless, the available published material does not yet convey the background, STELLA models, related teacher-support materials, and guidance on teaching methods that already exist in scattered places in the work of teachers who are pioneering in systems thinking and learner-directed learning.

Courageous and forceful action is needed and justified. Such action might best be led by private individuals rather than waiting for public political organizations to initiate innovation. Private support can operate with a freedom and a dedication of purpose that is not possible with the bureaucratic processes of government.

For most rapid progress, two kinds of activity are needed. One would be a diverse network of schools (starting with a few and expanding as progress justifies) that are experimenting with how best to introduce system dynamics and learner-directed learning into classrooms. The other activity would be a center serving as a focal point to maintain communication between the network of schools, expand the presently available training seminars for teachers, assist teachers in preparing their new materials for wider dissemination, and assist in maintaining the integrity and real-world practicality of the systems content of the emerging curriculum.

The effort will take substantial time. It must be planned and funded for adequate continuity. Both the network of schools and the focal-point center should have guaranteed funding for a decade or more. Additional funding will be needed for related activities in publishing, trial teaching, and retraining of teachers.

Unless the initial plan provides a time horizon long enough for effective launching of a radically improved process of education, it will not be possible to attract the necessary quality and breadth of talent. In addition to a core of experts in

[4] Although not written specifically for pre-college use, the following books can be helpful: (Forrester 1961, 1968, 1969, and 1973; Goodman 1974; and Richardson and Pugh 1981)

system dynamics, there must be even larger groups that understand the related aspects of a successful educational innovation— experienced teachers who understand the problems and opportunities in class rooms, people with past success in achieving improvement in education, those who can translate ideas into effective teaching materials, and practical inputs on how to draw together the strength that can come from mutual support from teachers, school administrators, school boards, parents, concerned public, and state and national school officials.

The initial challenge is to pull together a group of citizens with the vision, courage, financial resources, and concern for the long-term well-being of society that would take a leadership role in creating the working groups for a far more effective educational system than is otherwise likely to evolve.

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